

Third Edition

STRUCTURAL GEOLOGY

Marland P. Billings

*Professor of Geology
Harvard University*

Prentice-Hall, Inc.,
Englewood Cliffs, New Jersey

© 1972, 1954, 1942 by Prentice-Hall, Inc.
Englewood Cliffs, New Jersey

All rights reserved. No part of this book
may be reproduced in any form or by any means
without permission in writing from the publisher.

10 9 8 7 6 5

ISBN: 0-13-853846-8

Library of Congress Catalog Card Number 73-167628

Printed in the United States of America

PRENTICE-HALL INTERNATIONAL, INC., *London*
PRENTICE-HALL OF AUSTRALIA, PTY. LTD., *Sydney*
PRENTICE-HALL OF CANADA, LTD., *Toronto*
PRENTICE-HALL OF INDIA PRIVATE LIMITED, *New Delhi*
PRENTICE-HALL OF JAPAN, INC., *Tokyo*

PF

CONTENTS

1. Structural Geology, 1

Relation of Structural Geology to Geology, 1
Objectives of Structural Geology, 2
Scope of this Book, 6
References, 7

2. Mechanical Principles, 9

Materials of Structural Geology, 9
Force, 11
Stress, 16
Strain, 18
Stress-Strain Diagrams, 21
Factors Controlling Behavior of Materials, 23
References, 34

3. Description of Folds, 35

- Introduction, 35
- Attitude of Beds, 36
- Parts of a Fold, 37
- Nomenclature of Folds, 44
- Plunge of Folds, 58
- Refolding, 65
- Fold Systems, 66
- References, 69

4. Field Study of Folds, 71

- Recognition of Folds, 71
- Determination of Top of Beds of Primary Features, 81
- Drag Folds, 90
- References, 93

5. Office Techniques Used in Studying Folds, 95

- Introduction, 95
- Equal-Area and Stereographic Projections, 96
- Pi Diagrams, 100
- Contour Diagrams, 104
- Beta Diagrams, 107
- Use of Computers in Geology, 109
- Preparation of Pi Diagrams and Beta Diagrams by Computer, 110
- Structure Contour Maps, 112
- Calculating the Depth of Folding, 114
- References, 117

6. Mechanics and Causes of Folding, 118

- Introduction, 118
- Types of Folding, 118
- Dynamics of Folding, 124
- Ultimate Causes of Folding, 127
- References, 138

7. Joints, 140

Observational Data, 140
Principles of Failure by Rupture, 151
Genetic Classification of Joints, 168
References, 172

8. Description and Classification of Faults, 174

General Characteristics, 174
Nature of Movement Along Faults, 177
Classifications, 191
References, 198

9. Criteria For Faulting, 199

Introduction, 199
Discontinuity of Structures, 200
Repetition and Omission of Strata, 200
Features Characteristic of Fault Planes, 201
Silicification and Mineralization, 203
Differences in Sedimentary Facies, 203
Physiographic Criteria, 204
Distinction Between Fault Scarps, Fault-line Scarps,
and Composite Fault Scarps, 208
Map Symbols, 210
References, 212

10. Reverse Faults, Thrust Faults, and Overthrusts, 214

Introduction, 214
Thrusts and Reverse Faults, 214
Overthrusts, 217
Detachment Faults, 226
Megabreccias, 227
Mechanics of Reverse Faulting, Thrust Faulting, and
Overthrusts, 229
Palinspastic Maps, 242
References, 242

11. Normal Faults, 244

Introduction, 244
Size, Attitude, and Pattern, 245
Tilted Fault Blocks, 245
Horsts and Graben, 249
Modern Faults, 252
Renewed Faulting, 256
Mechanics of Normal Faulting, 257
References, 260

12. Strike-Slip Faults, 261

Introduction, 261
Examples of Strike-Slip Faults, 262
Rate of Displacement, 269
Fracture Zones of the Ocean Basins, 272
Mechanics of Strike-Slip Faults, 273
Shears of the Second Order, 274
References, 275

13. Dating of Structural Events, 277

Introduction, 277
Paleontology, 278
Unconformities, 278
Distinguishing Faults From Unconformities, 287
Radiogenic Dating, 289
Tectonism and Sedimentation, 290
References, 292

14. Diapirs and Related Structural Features, 293

Introduction, 293
Evaporite Diapirs, 294
Serpentine Diapirs, 302
Sedimentary Vents, 302
Mudlumps, 304
References, 305

15. Extrusive Igneous Rocks, 306

Introduction, 306
Lava Flows, 307
Pyroclastic Rocks, 308
Fissure Eruptions, 310
Volcanoes, 310
Craters, Calderas, and Related Forms, 312
Inflation and Deflation of Volcanoes, 321
References, 323

16. Intrusive Igneous Rocks, 326

Introduction, 326
Texture and Internal Structure, 327
Age Relative to the Adjacent Rocks, 330
Basis of Classification of Plutons, 331
Concordant Plutons, 335
Discordant Plutons, 350
Batholiths and Stocks, 361
References, 363

17. Emplacement of Large Plutons, 365

Introduction, 365
Time of Emplacement, 366
Depth of Emplacement, 368
Methods of Emplacement, 369
Forceful Injection, 372
Granite Tectonics, 372
Structures of the Flow Stage, 373
Structures of the Solid Stage, 377
Distinction between Primary and Secondary Structures, 378
Magmatic Stopping, 381
Metasomatic Replacement, 382
Relative Importance of Various Mechanisms, 383
Source of Magma, 383
References, 385

18. Cleavage and Schistosity, 386

Introduction, 386
Descriptive Terminology, 389
Origin, 393
Relation of Cleavage and Schistosity to Major Structure, 400
References, 407

19. Secondary Lineation, 408

Introduction, 408
Kinds of Secondary Lineation, 409
Attitude and Symbols, 413
Origin, 413
Successive Lineations, 417
Relation of Minor Structures to Overthrusts, 418
Lineaments, 419
References, 419

20. Plastic Deformation, 420

Introduction, 420
Evidence of Strain, 420
Mechanics of Plastic Deformation, 423
Dynamic Analysis of Petrofabric Diagrams, 428
Rotated Minerals, 432
Tectonites, 435
References, 436

21. Impact Structures, 437

Introduction, 437
Physical Features, 437
Shatter Cones, 440
Mineralogy, 441
Mechanics of Impacts, 441
Lunar Geology, 441
References, 443

**22. Geophysical Methods in Structural Geology:
Gravitational and Magnetic, 446**

Introduction, 446
Geophysical Methods, 447
Gravitational Methods, 448
Magnetic Methods, 458
References, 473

**23. Geophysical Methods in Structural Geology:
Seismic and Thermal, 475**

Seismic Methods, 475
Electrical Methods, 490
Radioactive and Thermal Methods, 490
References, 492

Laboratory Exercises, 493

1. Outcrop Pattern of Horizontal and Vertical Strata, 494
2. Patterns of Dipping Strata; Three-Point Problems, 499
3. Thickness and Depth of Strata, 507
4. Apparent Dips and Structure Sections of Folded Strata, 521
5. Geometrical Construction of Folds, 527
6. Structure Contours and Isopachs, 534
7. Trigonometric Solution of Fault Problems, 540
8. Projections, 546
9. Measurements by Descriptive Geometry, 551
10. Solution of Three-Point Problems and Vertical Fault Problems by Descriptive Geometry, 559
11. Solution of Inclined Fault Problems by Descriptive Geometry, 564
12. Equal-Area Net, Part I, 570
13. Equal-Area Net, Part II, 576
14. Use of Equal-Area Net Involving Rotation, 581

Equal-Area Net, 589

Index, 591